The Lake Baikal neutrino experiment

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We review the present status of the Baikal Neutrino Project and present the results of a search for high energy neutrinos with the detector intermediate stage *NT-96*.

1. Detector and Site

The Baikal Neutrino Telescope is deployed in Lake Baikal, Siberia, 3.6 km from shore at a depth of 1.1 km. *NT-200*, the medium-term goal of the collaboration [1], was put into operation at April 6th, 1998 and consists of 192 optical modules (OMs) – see fig.1. An umbrella-like frame carries 8 strings, each with 24 pairwise arranged OMs. Three underwater electrical cables connect the detector with the shore station.

In April 1993, the first part of *NT-200*, the detector *NT-36* with 36 OMs at 3 strings, was put into operation and took data up to March 1995. A 72-OM array, *NT-72*, run in 1995-96. In 1996 it was replaced by the four-string array *NT-96*. *NT-144*, a six-string array with 144 OMs, was taking data in 1997-98.

Summed over 1140 days effective lifetime, $6.6 \cdot 10^8$ muon events have been collected with *NT-36, -72, -96, -144, -200*.

The OMs are grouped in pairs along the strings. They contain 37-cm diameter *QUASAR* PMs which have been developed specially for our project [1–3]. The two PMs of a pair are switched in coincidence in order to suppress background from bioluminescence and PM noise. A pair defines a *channel*.

A *muon-trigger* is formed by the requirement of $\geq N$ *hits* (with *hit* referring to a channel) within 500 ns. N is typically set to 3 or 4. For such events, amplitude and time of all fired channels are digitized and sent to shore. A separate *monopole trigger* system searches for clusters of sequential hits in individual channels which are characteristic for the passage of slowly moving, bright objects like GUT monopoles.

The main challenge of large underwater neu-

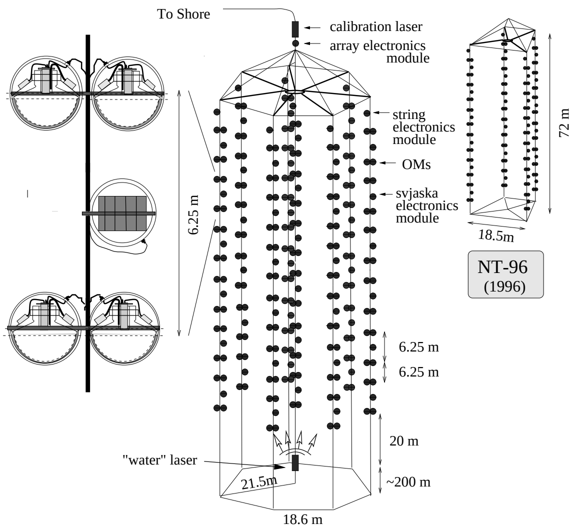

Figure 1. Schematic view of the Baikal Telescope *NT-200*. The expansion left-hand shows 2 pairs of optical modules ("svjaska") with the svjaska electronics module, which houses parts of the read-out and control electronics. Top right, the 1996 array *NT-96* is sketched.

trino telescopes is the identification of extraterrestrial neutrinos of high energy. In this paper we present results of a search for neutrinos with $E_\nu > 10\,\mathrm{TeV}$ obtained with the deep underwater neutrino telescope *NT-96* at Lake Baikal [4,5].

2. Search strategy and the limits on the diffuse neutrino flux

The used search strategy for high energy neutrinos relies on the detection of the Cherenkov light emitted by the electro-magnetic and (or) hadronic particle cascades and high energy muons produced at the neutrino interaction vertex in a large volume around the neutrino telescope.

We select events with high multiplicity of hit channels corresponding to bright cascades. The volume considered for generation of cascades is essentially *below* the geometrical volume of *NT-96*. A cut is applied which accepts only time patterns corresponding to upward traveling light signals (see below).

Neutrinos produce showers and high energy muons through CC-interactions

$$\nu_l(\bar{\nu}_l) + N \xrightarrow{CC} l^-(l^+) + \text{hadrons}, \qquad (1)$$

through NC-interactions

$$\nu_l(\bar{\nu}_l) + N \xrightarrow{NC} \nu_l(\bar{\nu}_l) + \text{hadrons}, \qquad (2)$$

where $l = e$ or μ, and through resonance production [6–8]

$$\bar{\nu_e} + e^- \rightarrow W^- \rightarrow \text{anything}, \qquad (3)$$

with the resonant neutrino energy $E_0 = M_w^2/2m_e = 6.3 \cdot 10^6\,\mathrm{GeV}$ and cross section $5.02 \cdot 10^{-31}\mathrm{cm}^2$.

Within the first 70 days of effective data taking, $8.4 \cdot 10^7$ events with $N_{hit} \geq 4$ have been selected.

For this analysis we used events with $\geq$4 hits along at least one of all hit strings. The time difference between any two channels on the same string was required to obey the condition:

$$\mid (t_i - t_j) - z_{ij}/c \mid < a \cdot z_{ij} + 2\delta, \;\; (i < j). \qquad (4)$$

The t_i, t_j are the arrival times at channels i, j, and z_{ij} is their vertical distance. $\delta = 5$ nsec accounts for the timing error and $a = 1$ nsec/m.

8608 events survive the selection criterion (4). The highest multiplicity of hit channels (one event) is $N_{hit} = 24$.

Since no events with $N_{hit} > 24$ are found in our data we can derive upper limits on the flux of high energy neutrinos which produce events with multiplicity

$$N_{hit} > 25. \qquad (5)$$

The shape of the neutrino spectrum was assumed to behave like E^{-2} as typically expected for Fermi acceleration. In this case, 90% of expected events would be produced by neutrinos from the energy range $10^4 \div 10^7\mathrm{GeV}$. Comparing the calculated rates with the upper limit to the actual number of events, 2.3 for 90% CL we obtain the following upper limit to the diffuse neutrino flux:

$$\frac{d\Phi_\nu}{dE} E^2 < 1.4 \cdot 10^{-5}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{GeV}. \qquad (6)$$

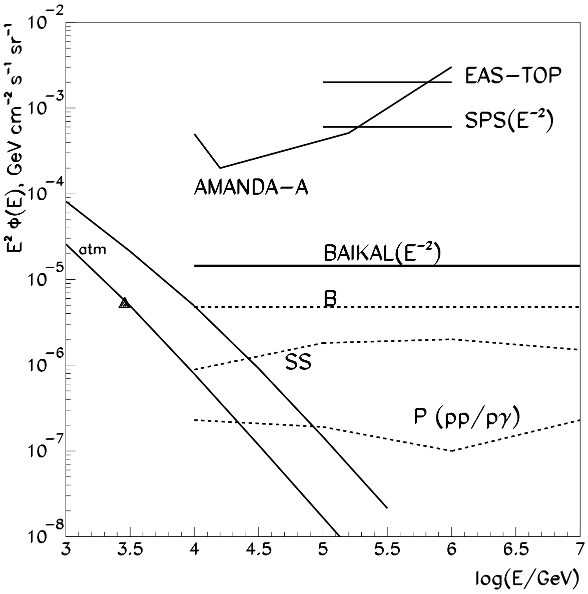

Figure 2. Upper limits to the differential flux of high energy neutrinos obtained by different experiments as well as upper bounds for neutrino fluxes from a number of different models. The triangle denotes the FREJUS limit.

Fig.2 shows the upper limits to the diffuse high energy neutrino fluxes obtained by BAIKAL (this work), SPS-DUMAND [9], AMANDA [10], EAS-TOP [11] and FREJUS [12] (triangle) experiments as well as model independent upper limit obtained by V.Berezinsky [13] (curve labelled B) (with the energy density of the diffuse X- and gamma-radiation $\omega_x \leq 2 \cdot 10^{-6}$ eV cm^{-3} as follows from EGRET data [14]) and the atmospheric neutrino fluxes [15] from horizontal and vertical directions (upper and lower curves, respectively). Also, predictions from Stecker and Salamon model [16] (curve labelled SS) and Protheroe model [17] (curve labelled P) for diffuse neutrino fluxes from quasar cores and blazar jets are shown in Fig.2.

For the resonant process (3) our 90% CL limit at the W resonance energy is:

$$\frac{d\Phi_{\bar{\nu}}}{dE_{\bar{\nu}}} \leq 3.6 \times 10^{-18} \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{GeV}^{-1}. \qquad (7)$$

The limit (6) obtained for the diffuse neutrino flux is of the same order as the limit announced by FREJUS [12] but extends to much higher energies. We expect that analysis of 3 years data taking with *NT-200* would allow us to lower this limit by another order of magnitude.

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